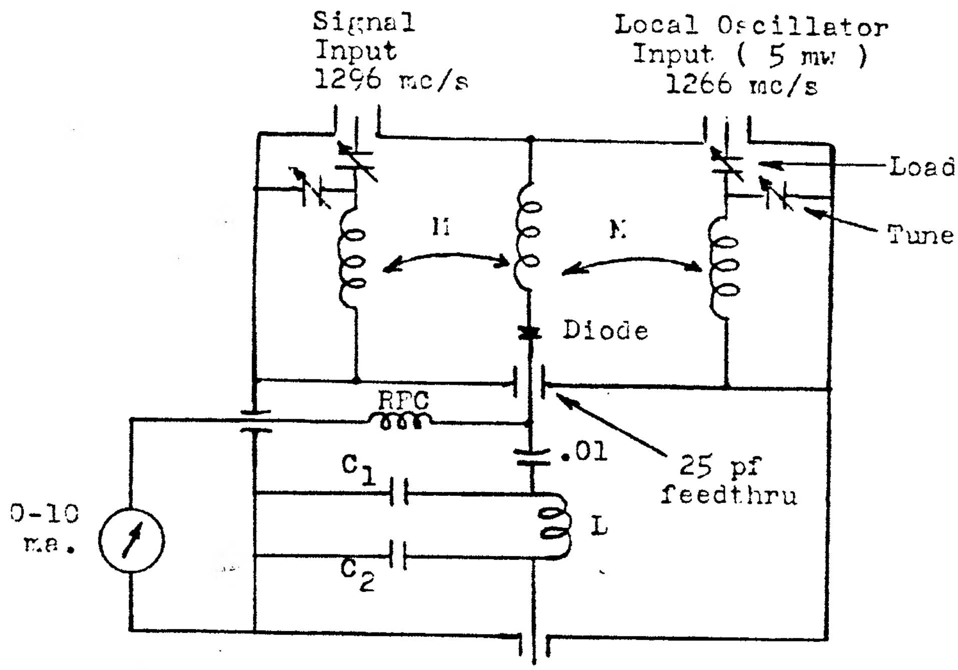
TECHNICAL REPORT NR 17

Date: Sept. 1974
From: The Crawford Hill VHF Club, W2NFA
Subject: A Low Noise Converter for 1296 mc/s

This report describes a low noise frequency converter for 1296 mc/s to 30 mc/s IF using a single inexpensive Hewlett-Packard "hot carrier" diode based on a design by R. E. Fisher, W2CQH *. The circuit is narrow band and uses single pole interdigital resonators for separation of signal and local oscillator voltages to insure SSB performance. This design differs from that of Fisher's by substituting adjustable capacitive coupling at the signal and L.O. inputs instead of the fixed inductive coupling. The local oscillator power source is not included in this design.

This report is intended for those experimenters who would like more information and variation on an excellent converter design. All are urged to consult the reference.

The converter to be described in this report is shown schematically below.



C_1 = 80 pf - $C_{feedthru}$

C_2 = 120 pf

L = 0.45 uhy

Q = 3

* QST January 1974

The π impedance matching network at the mixer output (C_1, C_2 and L) should be located at the mixer. Unlike the Fisher design, the IF output impedance for minimum NF was found to be about 200 ohms at the diode and the IF preamplifier is separated from the mixer at a 50 ohm interface impedance level. The impedance transformer which includes the 25 pf feedthru by pass capacitor as part of the network has an impedance ratio of about 4;1 and is not critical.

The working IF may be moved to 28 mc/s for convenience but should not be moved much below this frequency because of the selectivity of the r-f resonators. When this circuit is optimized for best SSB low noise performance the image rejection is about 16 to 20 db and the L.O. signal is rejected at the signal port by a similar amount. If these rejection levels are objectionable or there is evidence of strong interefcrence at the image frequency (60 mc/s below the signal frequency in this case) an interdigital filter of the type described by Fisher * may be connected to the signal port. Keep in mind that the L.O. and image frequencies should be in the stop band of the filter.

The L.O. level must be sufficient to drive the rectified diode current to about 4 ma for optimum performance. This is not critical but must be over 1 ma for satisfactory performance. The L.O. level may be adjusted by means of the capacitive coupling. This coupling should be measurably less than at the signal port to assure a higher-Q in the L.O. resonator which results in little signal energy loss in the L.O. circuitry. For this reason, the available L.O. power should be at least 5 mw. The diode d-c return path, r-f choke and meter should have low resistance. If the meter is removed a strap should replace it.

The r-f resonators and diode coupling construction are exactly as in the Fisher design which essentially limits the resonator maximum loaded Q. This design assumes that the pumped diode r-f impedance is nearly 50 ohms, an assumption which is very reasonable judging by the mixer circuit performance.

Construction

Details and dimensions of the mixer circuit construction are shown by Figure 1. The broad walls of the enclosure may be made of 1/16 inch sheet brass or copper. Copper clad printed circuit board is also acceptable. The resonators are made from 3/8 inch O.D. hard drawn copper tube while the coupling post is a brass rod 1/2 inch O.D. (outside diameter - not critical) and tapered as shown to minimize stray capacitance where the diode is connected. The grounded ends of the resonators and coupling post may be bolted securely as shown or alternatively soldered carefully in place. Experience has indicated that the highest Q for these resonators is obtained by carefully mating the resonator to the brass bar before drawing tight or soldering. Soldering is not required if the inside chamfered edge shown in the detail on Figure 1 is used.

The adjustable coupling capacitors are small metal discs which pass through the mounting hole of the BNC jack and are soldered to the jack pin. Capacitor adjustment is by means of the threaded barrel of the UG 625 B/U jack in the 3/8-32 tapped hole.

Resonator tuning is by means of the strip tab soldered to the broad wall and pressed toward the resonator by the insulated screw.

* QST March 1968

Unlike the Fisher design, the narrow sides of the resonator enclosure must be covered to prevent leakage radiation. Strips of P.C. board may be secured to the brass bars on either side (not shown by drawings). The corners need not be electrically tight since resonator field current is along the axial direction and no leakage will occur through the axial slits.

Mounting of the diode which is physically small and has wire leads is detailed by Figure 2. Two methods of r-f bypass are shown. The diode wire lead is first soldered into the bypass plate or button capacitor with zero lead length. Do this quickly with a fairly hot small tipped iron so as not to damage the diode. Diode polarity is not important to the operation of this circuit. After the bypass capacitor is secured in its mounting place, the other end of the diode may be tack soldered to the soft thin copper tab at the end of the coupling post. This copper tab provides not only a low inductive connection to the diode but also a very important soft mechanical mount to prevent strain and diode breakage. It would be wise to solder the diode in at the very last.

Capacitor C_2 may be a small ceramic trimmer in order to optimize the match.

If it is desirable to include the IF preamp with the mixer as in the Fisher design, the space occupied by the matching network may be expanded to include the preamp. A single π network matching 200 to about 1500 ohms will now be required.*

As in all UHF construction care, cleanliness and good surface joints are essential to success. Since the brass bars and sidewalls are part of the resonator construction it is recommended that the bars be lapped clean and flat on all surfaces especially the narrow sides which join to the broad walls. Lapping is conveniently done by taping a sheet of medium fine emory cloth or fine sandpaper to a flat surface. The brass bars may be hand held between square wooden blocks for accuracy and then rubbed in a figure '8' pattern until the entire surface has been worn down evenly. The broad wall material should also be checked for flatness especially where the brass bars are joined. All drilling burrs must be removed to insure good joints.

One of the broad wall plates may be permanently soldered to the bars the other should be removable.

Tune-Up

Initially a suitable local oscillator source should be connected to the L.O. port and the L.O. resonator tuned for resonance as indicated by maximum rectified diode current. Then adjust the coupling for about 4 ma of diode current and trim the resonator tuning.

Next a suitable IF preamplifier and linear noise measuring receiver are connected to the IF output. If automatic noise measuring equipment is available the tune-up consists of first resonating the signal circuit for maximum response at 1296 mc/s and then making small adjustments of input coupling and IF output tuning (C_2) for minimum NF.

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* A. R. R. L. Handbook, 1967 page 49.

Without automatic measuring gear, the procedure is essentially the same but more tedious since the noise source must be turned ON and OFF after each adjustment. It is not necessary to have a calibrated noise source for the tune-up, just a stable one. The object is to adjust for maximum difference in receiver output noise from ON to OFF of the noise source.

If no measuring gear is available, set the coupling capacitor gaps as per the dimensions in Figure 1 and adjust the signal resonator at 1296 mc/s using a weak signal from your exciter or from a nearby station on 1296 mc/s. The use of on-the-air testing signals should be used as a last resort since the uncertainty of signal level over a period of time may be considerable.

It is recommended that a 50 ohm 10 db pad be connected to the converter input during initial signal tune-up adjustments to insure that the signal source impedance is close to 50 ohms. Do not use a pad for noise measurements but do know the noise source impedance, which should be near 50 ohms.

If this converter is to be used directly with an antenna whose feedline is not well matched or of unknown match, some trimming of the signal loading and tuning may be required. Similarly with a preamplifier of unknown output impedance trimming will be required.

Some Theory

Conversion of radio frequencies is accomplished by mixing two or more signals in a non-linear circuit element. A receiving down converter usually employs a non-linear resistive element (a semiconductor diode) which translates a high rf signal down to some lower frequency called the intermediate frequency, IF. To accomplish the frequency translation it is necessary to introduce a second RF signal (local oscillator) above or below the signal frequency by an amount equal to the IF. Ideally the non linear element should behave as a lossless switch driven by the L.O. signal. In practice diodes used in UHF mixers can approach ideal characteristics when driven with sufficient power at the L.O. freq uency and used in an appropriate circuit.

In a receiving down conterter the frequency translation from RF to IF should be accomplished with good efficiency (low conversion loss) and the mixing element should introduce a minimum of extra noise. Mixers designed around good quality Schottky barrier ('hot carrier') type diodes can be characterized by a noise factor equal to the noise factor of the IF amplifier, F_{IF}, multiplied by the conversion loss, L, expressed as a number greater than 1.

$$F_{mixer} = F_{if} L$$

In decibel form, $F_{mixer} = F_{IF}(db) + L\ (db)$.

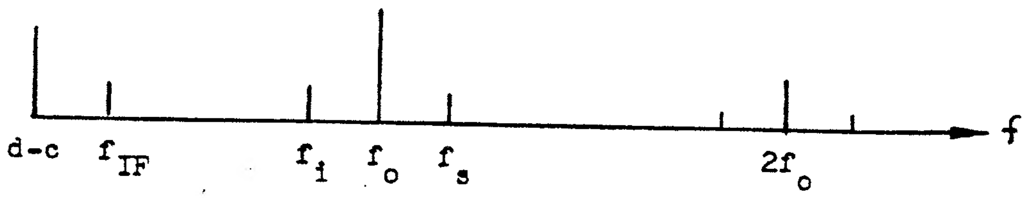
For example, if the IF amplifier noise figure is 1.5 db and the mixer conversion loss is 6 db, then the combined mixer plus IF amplifier noise figure is 7.5 db. The equivalent temperature of the mixer is then the usual formula

$$T_{mixer} = (F_{mixer} - 1)\ 290^{\circ}K$$

It is evident that the overall NF may be decreased by using as low an IF noise figure as possible and or reducing the conversion loss. A practical limit on the IF noise figure is about 1 db in the HF and VHF region using bipolar transistors. Lower IF noise figures can be achieved but with considerable more difficulty. Current FETs and MOSFETs are around 1.5 db noise figure in the same region.

Conversion loss can be considered separately. In a mixer the local oscillator power level must be much greater than the signal level in order to affect an efficient linear amplitude conversion. Unfortunately the large local oscillator level impressed on a non-linear element produces harmonics of the local oscillator frequency. In addition energy converted from the signal frequency to the IF will modulate the local oscillator and its harmonics and appear as sidebands on either side of the L.O. and its harmonics. The sideband associated with the L.O. fundamental is called the image frequency.

A spectral diagram of frequencies which appear across the diode terminals is shown below.



It is intuitively obvious that if energy is dissipated at all the sidebands, less will be available at the IF. It is therefore desirable to reactively terminate all sidebands except the signal frequency and the IF. A rigorous analysis indicates that the image frequency, f_i, is most important and should be terminated by an open circuit effectively across the diode terminals. This process is sometimes referred to as image enhancement or image recovery in a mixer circuit.

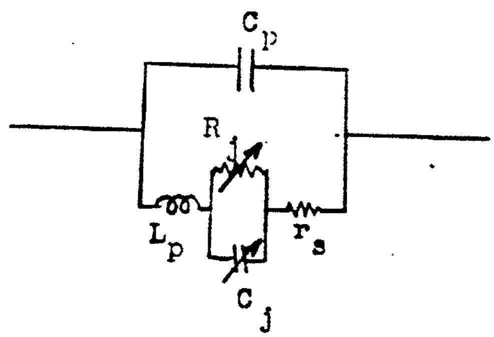
Next in importance are the sidebands on either side of the second harmonic of the local oscillator frequency, $2f_o \pm f_{IF}$. Although it is desirable to open circuit these sidebands, it is an impractical circuit problem and therefore more expedient to suppress the second harmonic of the local oscillator by means of a short circuit effectively across the diode terminals at $2f_o$. Treatment of higher harmonics depends on the diode quality in generating higher harmonics. In general an open circuit at the image frequency and a short circuit at $2f_o$ accounts for most of the available improvement in conversion loss. Little improvement will be achieved by treating higher harmonics of the local oscillator.

Diode quality can be described in terms of the ratio of its cut-off frequency to the operating frequency. The cut-off frequency is defined in the usual way

$$f_{co} = \frac{1}{2\pi r_s C_j} ,$$

where r_s is the bulk spreading resistance of the diode and C_j is the average junction capacitance under full local oscillator drive. In general C_j will be very nearly equal to the small signal junction capacitance at zero bias, a value usually available from the manufacturers specifications. A value for r_s is also usually specified. Both can be measured with proper equipment. Analysis of the minimum conversion loss of a Schottky barrier diode mixer, neglecting circuit losses indicates that for a ratio of f_{co}/f_s, of 20, L_{min} is 3 db. And for a ratio of 100, L_{min} is 1.5 db. In practice these minima cannot be achieved and measurement data indicates that corresponding values for L should be increased by 1 db. In addition, the spreading resistance, r_s, should be as low as possible. If two diodes have nearly the same cut-off frequency, the one with the lower r_s will give slightly better performance.

An additional factor which must be considered is the series résonance of the diode junction capacitance and the inevitable inductance which takes the form of a contact wire or strap. This strap is also required to take up thermal stresses and is therefore usually folded or bent which increases its inductance. The equivalent citcuit of a Schottky barrier diode of the wire lead glass encapsulated type is shown below.



C_p is the package capacitance which is resonated at the image frequency to open circuit the diode terminals. L_p is the package inductance described above and does not include the wire leads of the diode. The equivalent circuit shown above is contained within a very tiny volume at the center of the glass bead which supports the wire leads. The series resonance considered here is for the circuit elements L_p and C_j. If this series resonance is near or on the second harmonic of the local oscillator all efforts to short circuit the diode will not reduce the second harmonic sideband losses. It is therefore a further requirement of the diode that its natural series resonance be well above the second harmonic of the local oscillator.

Typically for the Hewlett Packard glass bead diodes, L_p is about 2×10^{-9} henries and C_j under drive conditions will be about 1 to 1.2 $\times 10^{-12}$ farads. Series resonance will therefore lie in the region around 4 Gc which is adequate for 1296 mc/s operation but is marginal for 2300 mc/s operation. For this particular encapaulation it is therefore suggested that diodes with minimum C_j be chosen in order to increase series resonance above the local oscillator second harmonic. A better approach is to use a different diode encapsulation more suitable for higher frequency operation, such as the beam lead type.

Armed with these theoretical requirements it is instructive to analyze the mixer circuit designed by R. E. Fisher. The interdigital resonators are single pole narrow band filters tuned to the signal and local oscillator frequencies. The central rod is an inductively coupled non-resonant line terminated by the diode. The RF impedance of the diode is approximately 50 ohms at either signal or LO frequencies. At frequencies other than f_s and f_o the central rod can be considered as an isolated unterminated section of line whose characteristic impedance is about 50 ohms.

At f_{image} the rod is approximately a quarter wavelength long and together with the case capacitance of the diode a parallel resonance is affected across the diode terminals. This is more nearly valid when the image frequency is below the local oscillator frequency, as shown by the spectral diagram. (It is of course possible to operate a mixer with the image and signal frequencies reversed in designation.) The Q of this image resonance is very low because the RF resistance of the diode is in shunt with the circuit impedance. It is therefore unnecessary to obtain exact parallel resonance, only in so far as the parallel resonant impedance is at least ten times the diode RF resistance of about 50 ohms This condition is relatively easy to realize without exact knowledge of the resonant frequency of the rod plus diode case capacitance.

Furthermore, the length of the central rod is very nearly a halfwave at the second harmonic frequency of the local oscillator. Since the end of the rod opposite the diode is grounded, the halfwave resonance presents an effective short circuit across the diode terminals at $2f_o$. This resonance although relatively critical in tuning so that an impedance much lower than 50 ohms is effected at the diode, is of lesser importance in terms of improving the conversion loss of the mixer circuit.

It is evident therefore that the interdigital mixer design of Fisher fullfills the primary circuit requirements for low conversion loss. In a quantitative accounting using an H.P. 5082-2835 diode which has a cut-off frequency of about 20 Gc the optimized noisefigure of the mixer plus 1.5 db IF was 5.5 db. Which indicates a conversion loss of 4.0 db which is approximately 0.5 db higher than the theoretical lower limit of 3.5 db for the ratio of 20Gc/1.3Gc. A remarkable accomplishment for so simple a circuit!!!

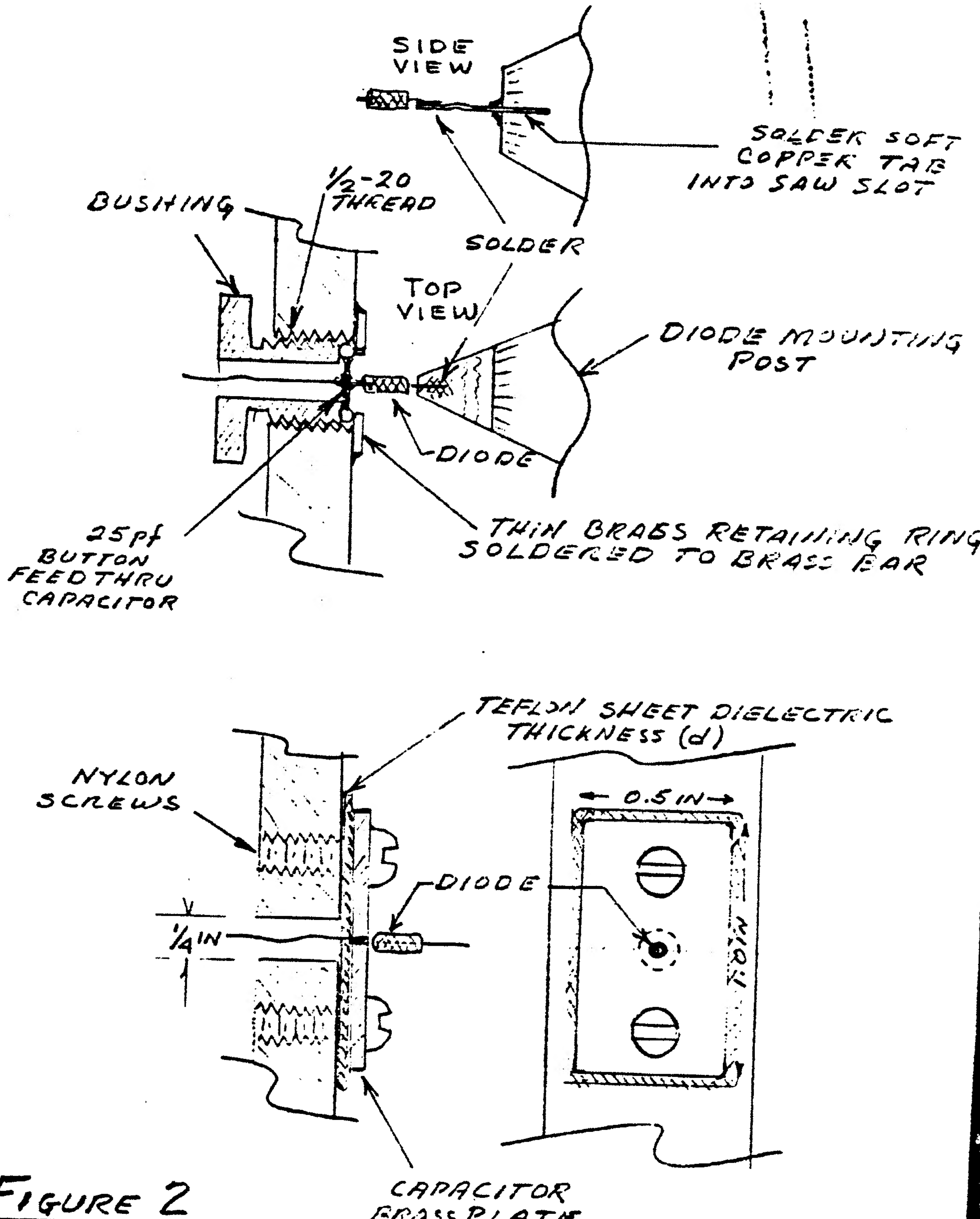
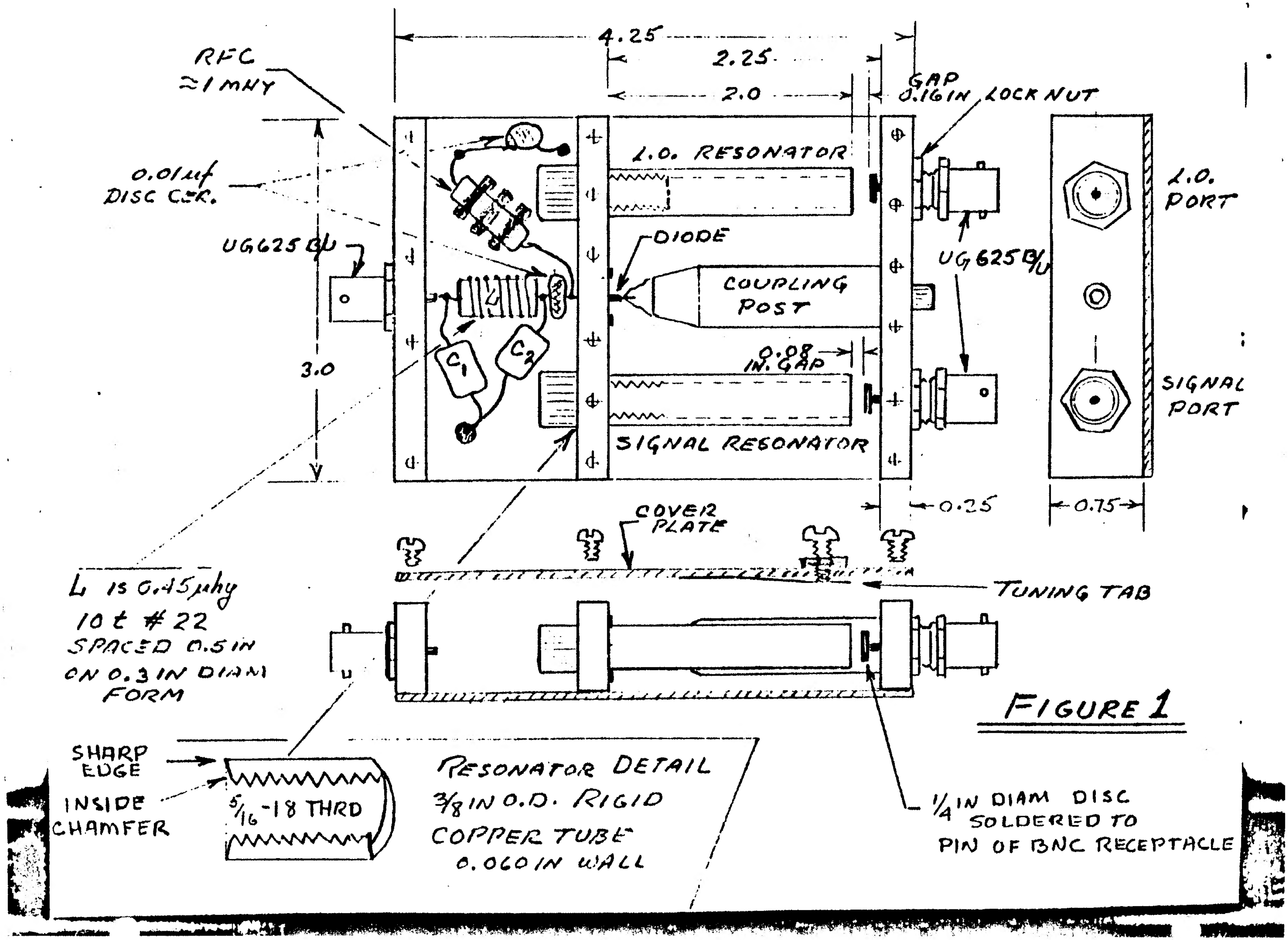


FIGURE 2

$$C_{pf} = 0.224\,\frac{KA}{d} \approx 25\,pf$$

$K = 2.0$ FOR TEFLON



4.25
2.25
2.0
RFC
≈1 MHY
GAP
0.16 IN LOCK NUT
L.O. RESONATOR
0.01 μf
DISC CER.
L.O.
PORT
DIODE
UG625 B/U
UG625 B/U
COUPLING
POST
0.08
IN. GAP
3.0
SIGNAL
PORT
SIGNAL RESONATOR
0.25
0.75
COVER
PLATE
TUNING TAB
L is 0.45 μhy
10 t #22
SPACED 0.5 IN
ON 0.3 IN DIAM
FORM
SHARP
EDGE
INSIDE
CHAMFER
5/16-18 THRD
RESONATOR DETAIL
3/8 IN O.D. RIGID
COPPER TUBE
0.060 IN WALL
1/4 IN DIAM DISC
SOLDERED TO
PIN OF BNC RECEPTACLE

FIGURE 1